Lat 40.316401 Lon -120.681461

Forest Health Protection
Pacific Southwest Region
Northeastern California Shared Service Area

Date: November 21, 2014
File Code: 3420

To: District Ranger, Eagle Lake Ranger District, Lassen National Forest

Subject: Forest Health Evaluation of the Diamond Mountain project (FHP Report NE14-08)

Summary

At the request of Bobette Jones, Ecologist, Eagle Lake Ranger District, I conducted a field evaluation of the proposed Diamond Mountain project area on September 25, 2014. The objective was to evaluate the current forest health conditions within the project area, discuss what influence these conditions would have on stand management objectives and provide recommendations as appropriate. Bobette Jones accompanied me to the field.

Key findings:

- Mixed conifer stands and Jeffrey pine stands have become denser with a higher proportion of white fir in the absence of fire. These stands are considered at an elevated risk for bark beetle-caused mortality, especially during extended droughts.
- High fuels loads, consisting of an abundance of dead-down trees (mostly white fir from the 1987-1992 drought event) and a dense understory of live trees; put many stands at risk to stand replacing wildfire.
- Dwarf mistletoe is impacting a few white fir stands causing branch dieback, bole deformities, and contributing to tree mortality on poorer growing sites.
- Heterobasidion root disease is present in many white fir stands contributing to mortality during droughts.
- Western pine beetle is causing mortality in dense pockets of ponderosa pine at lower elevations.
- Douglas-fir tussock moth-caused defoliation of white fir may lead to a slight increase in mortality next year.
- The current drought has the potential to increase tree mortality dramatically over the next couple of years.

Danny Cluck
Forest Entomologist
530-252-6431
dcluck@fs.fed.us

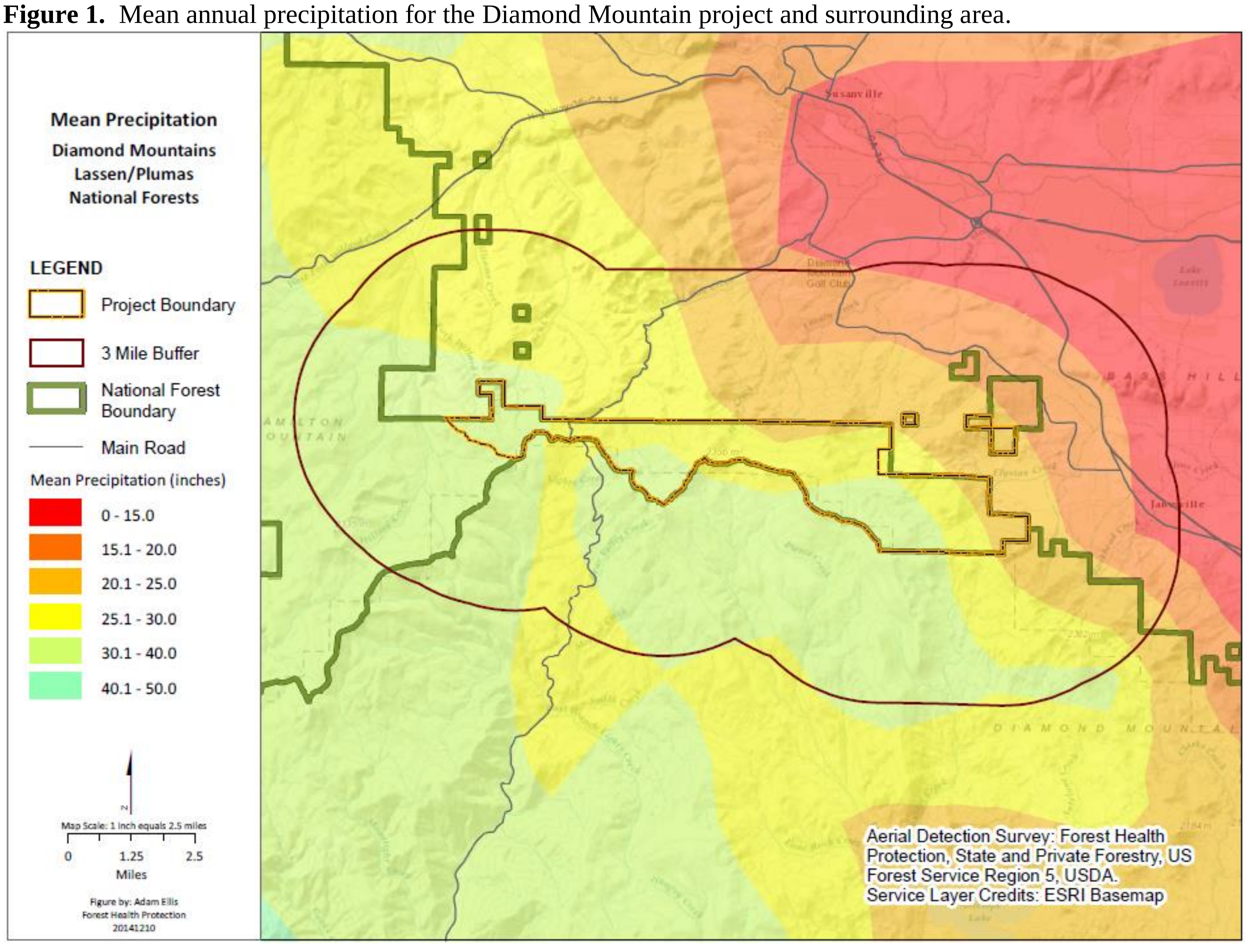
Bill Woodruff
Plant Pathologist
530-252-6880
wwoodruff@fs.fed.us

Thinning is recommended throughout the Diamond Mountain project area to reduce stocking to levels that increase the health and vigor of residual trees and reduce the abundance of white fir in some locations. Specific recommendations are provided in this evaluation.

Description of the project area

The Diamond Mountain Project is located 7 miles south of Susanville, CA (40.316401N, 120.681461W). The elevation of the site ranges from 4,300 to 7,700 feet with annual precipitation ranging from 20 to 40 inches (Figure 1). The majority of the project area consists of north facing slopes and drainages with the highest annual precipitation occurring at the upper elevations. Forest stands are comprised of red fir (*Abies magnifica*) with scattered western white pine (*Pinus monticola*) at upper elevation sites that retain more snow, Jeffrey pine (*Pinus jeffreyi*) and white fir (*Abies concolor*) on drier upper elevation sites and Sierra mixed conifer at mid and lower elevations. The Sierra mixed conifer consists of ponderosa pine (*Pinus ponderosa*), Jeffrey pine, sugar pine (*Pinus lambertiana*), white fir, Douglas-fir (*Pseudotsuga menziesii*) and incense cedar (*Calocedrus decurrens*). Riparian areas within the mixed conifer include lodgepole pine (*Pinus contorta*). Hardwoods are scattered throughout the project area and include black oak (*Quercus kelloggii*), bigleaf maple (*Acer macrophylum*), quaking aspen (*Populus tremuloides*), Scouler's willow (*Salix scouleriana*) and black cottonwood (*Populus trichocarpa*).

Figure 1. Mean annual precipitation for the Diamond Mountain project and surrounding area.



Management objectives

A variable thinning strategy is planned for most stands in the Diamond Mountain area with an emphasis placed on riparian and aspen restoration (conifer reduction), surface and ladder fuel reduction and reducing white fir abundance in mixed conifer stands. These types of treatments would begin to move stands to a more resilient condition that is consistent with Regional ecosystem restoration goals.

Forest insect and disease conditions

Agents/hosts observed from ground reconnaissance:

- Western pine beetle (*Dendroctonus brevicomis*)-caused mortality of ponderosa pine in the Baxter Creek drainage.
- Dwarf mistletoe (*Arceuthobium abietis*) in white fir throughout the project area with high infestation levels noted at Bear Flat and upper Cheney Creek.
- Heterobasidion root disease (*Heterobasidion occidentale*) in true fir (scattered throughout the project area at various levels).
- Jeffrey pine beetle (*Dendroctonus jeffreyi*)-caused mortality of a couple of large diameter Jeffrey pine in Gilman Basin.
- Fir engraver beetle (*Scolytus ventralis*)-caused mortality of white fir (scattered throughout the project area at low levels).
- Douglas-fir tussock moth (*Orgyia pseudotsugata*)-caused defoliation of white fir in the upper Willard and Cheney Creek area.
- Satin moth (*Leucoma salicis*)-caused defoliation of aspen west of Aspen Flat.

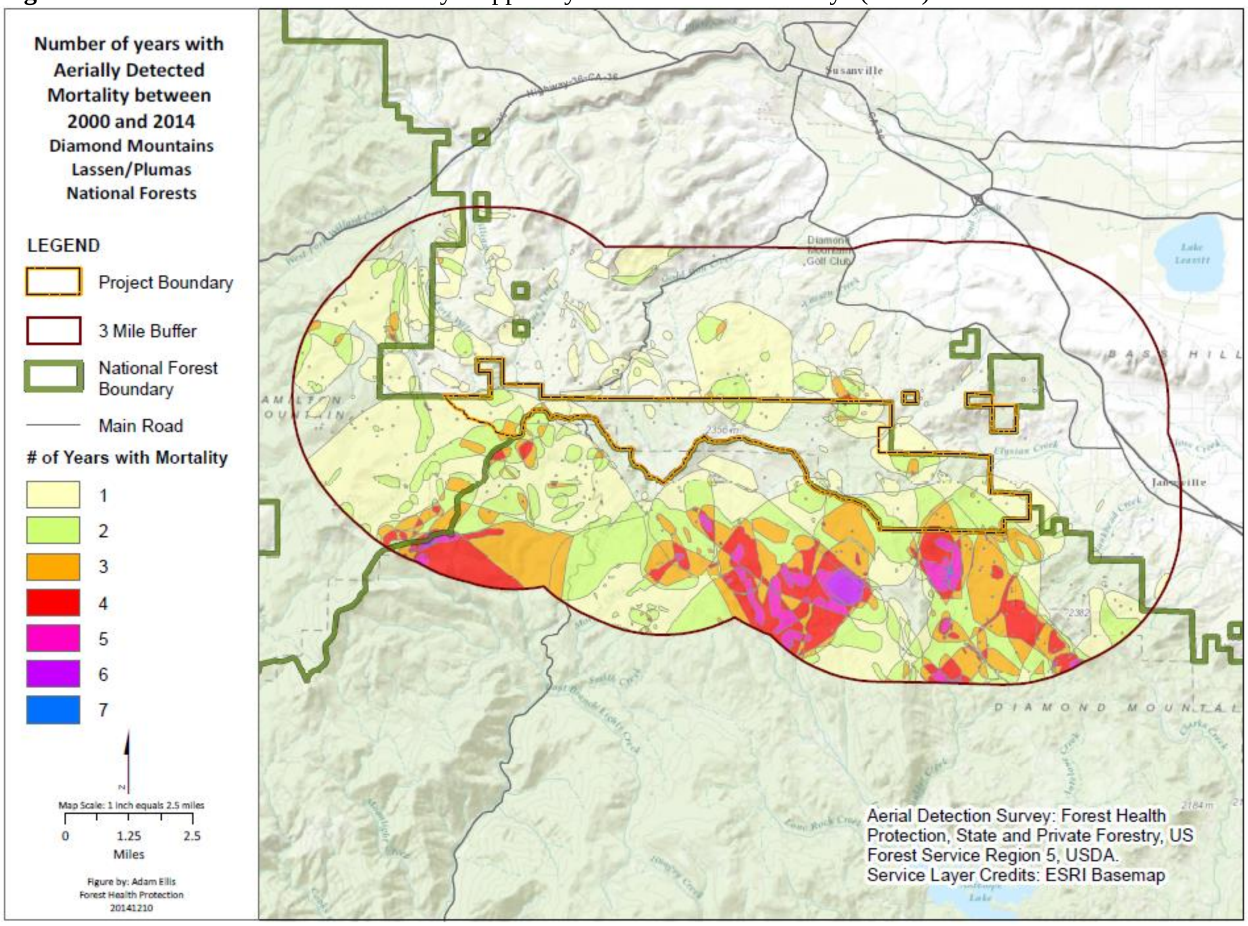
Agents/hosts detected from Aerial Detection Survey from 2005 to 2014 (Figure 2):

- 2005 - Elevated white fir mortality in Gilman Basin, upper Willard Creek, Bear Flat and Baxter Creek areas.
- 2007 - Scattered ponderosa pine mortality; small groups in Baxter Creek area.
- 2009 - Scattered large diameter sugar pine and Jeffrey pine mortality.
- 2010 - Elevated white fir mortality in Gilman Basin, Bear Flat and Aspen Flat; scattered aspen defoliation.
- 2011 - Elevated white fir mortality in upper Willard and Cheney Creeks, Jeffrey pine mortality near Bear Flat and ponderosa pine mortality near Baxter Creek.
- 2012 - Elevated ponderosa pine and white fir mortality in upper Willard and Cheney Creek areas; ponderosa pine and sugar pine mortality upper Gold Run Creek.
- 2013 - Elevated white fir mortality in upper Baxter Creek and scattered Jeffrey pine mortality west of Bear Flat.
- 2014 - Small pocket of Douglas-fir beetle (*Dendroctonus pseudotsugae*)-caused mortality in upper Elysian Creek

Stand conditions and mortality related to recent and future climate trends

Many of the forested areas within and adjacent to the Diamond Mountain project are in an overstocked condition; too many trees and high basal area exceeding the long-term carrying capacity of the site. This condition is revealed during drier years with elevated levels of tree mortality caused by bark beetles; especially fir engraver beetle-caused mortality of white fir (Table 1). These periodic mortality events combined with high stand density has led to heavy fuel loading in some areas and a corresponding increase in fire hazard.

Figure 2. Areas of elevated tree mortality mapped by Aerial Detection Surveys (ADS) between 2000 and 2014.



Successive dry years can exacerbate unhealthy stand conditions, such as those that exist within most Diamond Mountain project stands. This typically results in higher levels of bark beetle-caused tree mortality, especially in trees that are predisposed by other factors such as high stand density, dwarf mistletoe and root disease. Recent aerial detection surveys show how the successive dry years from 2007 to 2009 lead to increased levels of tree mortality from 2009 to 2012 in the Diamond Mountain area (Table 1). Although the majority of the mortality over the past 15 years has occurred in adjacent stands just south of the project area on drier south facing slopes (Figure 2), a major mortality event occurred on the north facing slopes and drainages within the project area 20 years ago.

Table 1. Acres with tree mortality, estimated dead trees per acre and estimated # of dead trees from R5 Aerial Detection Surveys and Palmer Hydrologic Drought Index (PHDI) (average of CA Divisions 2 and 3[1]) by water year (Oct-Sept) within and adjacent to the Diamond Mountain project area.

Year	Acres	Estimated Dead Trees/Acre	Estimated # of Dead Trees	PHDI[2]
2014	991	0.7	718	-3.56
2013	876	1.7	1,447	-2.16
2012	3,144	2.2	6,978	-0.59
2011	5,235	1.4	7,398	2.78
2010	5,284	1.8	9,538	-0.14
2009	755	3.1	2,349	-2.98
2008	194	1.1	208	-3.16
2007	34	1.0	34	-3.17
2006	85	1.0	84	2.40
2005	1,991	0.5	1,069	0.37

[1] California Divisions 2 and 3 encompass most of northeastern California. The Diamond Mountain project is on the border between these two zones.
[2] PHDI values ranging from -2.00 to -2.99 are considered moderate drought conditions. Severe drought conditions range from -3.00 to -3.99 and extreme drought conditions are below -4.00.

Approximately two thirds of the Diamond Mountain project area receives less than 30 inches of average annual precipitation (Figure 1). This is below what is generally required for healthy white fir forests. Therefore, even with lower stocking levels, white fir growing on these sites are at a higher risk for fir engraver beetle-caused mortality during periods of drought. High stand density combined with the prolonged drought of 1987-1992 resulted in elevated levels of white fir mortality throughout the project area as evidenced by older dead and down stems from that period. This mortality event resulted in several large timber salvage sales in the early 1990's that removed thousands of dead and dying trees. While the majority of the mortality consisted of white fir, significant losses of red fir, Jeffrey pine, ponderosa pine and sugar pine also occurred.

The distribution of both white fir and white fir mortality are strongly influenced by the mean annual precipitation. The lower limit of precipitation in the natural range of white fir is about 20 inches (Fowels, H.A. 1965). The isohyetal map of mean annual precipitation provided in this report (Figure 1) can be used to rate the risk of white fir mortality (Schultz 1994, FHP Report 94-2).

Low risk: 40+ inches annual precipitation (0% of Diamond Mountain project area). These areas easily support stands of white fir and red fir. Mortality will be low, even during drought periods. Thinning will increase the rate of tree growth, but will show only slight differences in tree mortality.

Medium Risk: 30-40 inches of annual precipitation (~50% of Diamond Mountain project area). Stands in these areas often have a high percentage of white fir that may achieve a considerable age and size. Prolonged drought may cause mortality of 5-10% of the stems. Periodic thinning which concentrates on removing white fir ingrowth will lower mortality by maintaining a more sustainable amount of biomass, as well as promoting a more stable mixed species stand.

High Risk: 25-30 inches of annual precipitation (~40% of Diamond Mountain project area). In the absence of fire, these areas have stands which are dominated by densely stocked, small

diameter white fir. The species distribution by age class shows an increase in the relative percentage of white fir in these stands following fire suppression. Prolonged drought may cause mortality in excess of 50% of the stems. The risk of mortality can be lowered by thinning to a wide spacing prior to the onset of drought, and by promoting a mix of species that are native to the site.

<u>Extreme risk: 20-25 inches of annual precipitation (~10% of Diamond Mountain project area).</u> In some cases the shade tolerant trees may live long enough to achieve an intermediate of co-dominant crown position. Prolonged drought may cause mortality of 80-85% of the stems. In stands where the total stocking of both overstory and understory is high, mortality may also occur in the pines. The risk of mortality may be lowered by managing groups of pine at wide spacing.

A white fir levels of growing stock study conducted by Cochran (1998) on the Deschutes and Fremont National Forests between 1983 and 1995 provides some additional information to consider when managing white fir in lower precipitation areas. Plots were thinned in 1982 and again in 1985 to a residual stand density index (SDI) of 112, 168, 224 or 280. These corresponded to growing stock levels of 20, 30, 40 or 50 percent of normal density. Elevations for his study plots ranged from 4,500 to 5,900 feet with average annual precipitation ranging from 16 to 31 inches. A general drought prevailed over the study areas from the late 1970’s to the mid 1990’s and mortality between 1991 and 1995 destroyed the study. Mortality on Blocks 2, 3 and 4 of the study was attributed to fir engraver beetles. Mortality from fir engraver beetles appeared to increase with increasing stand densities and was above acceptable levels even at the lowest stand density (20 percent of density considered normal for white fir).

Healthy stands of white fir grow very rapidly, produce a dense crown cover and are visually pleasing (Cochran 1998). Cochran’s results, however, raise doubts about maintaining stands with a large component of white fir in areas with mean annual precipitation below 32 inches even if stand densities are kept very low. Cochran’s study stands grew well for more than 60 years and reached commercial size before severe mortality occurred. With climate change predictions of warmer and possibly drier conditions in the future, the risk of white fir mortality in these areas will likely become even greater.

The current overstocked condition in most Diamond Mountain stands, as well as the overabundance of white fir in previously pine dominated stands, will continue to facilitate high levels of insect and disease activity. Large scale bark beetle outbreaks will likely occur periodically in response to extended drought periods. In the interim, older Jeffrey, sugar and ponderosa pine will continue to succumb to disease, drought and bark beetle attacks and slowly be replaced by dense stands of younger shade tolerant trees. White fir will continue to succumb to fir engraver beetles after being weakened by Heterobasidion root disease. Fuel loads will continue to increase creating a high risk of high intensity and stand replacing fire across all forest types.

Tree mortality tends to increase rapidly after two to three consecutive years of drought. In northeastern California, tree mortality rapidly increased in many locations after the dry years of 2000-2002 and 2007-2009. The current drought is now entering a third consecutive year based

on the Palmer Hydrologic Drought Index and is shaping up to be more extreme than these previous events. Even though significant tree mortality has yet to occur, the District should plan for a potentially sharp increase over the next couple of years within and adjacent to the project area.

Predicted climate change is likely to impact trees growing in the Diamond Mountain over the next 100 years. Although no Lassen National Forest specific climate change models are available at this time, there is a general consensus among California models that summers will be drier than they are currently. This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation (K. Merriam and H. Safford, *A summary of current trends and probable future trends in climate and climate-driven processes in the Sierra Cascade Province, including the Plumas, Modoc, and Lassen National Forests*). Under this scenario, the risk of bark beetle-caused tree mortality will likely increase for all conifer species, especially drought intolerant white fir. Improving the resilience of stands to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape.

Considerations for thinning treatments

Thinning treatments should be designed to achieve sustainable stocking levels and trend species compositions towards a more drought tolerant condition. This should effectively reduce inter-tree competition for limited water and nutrients and reduce the risk of insect and disease-caused mortality for most treatment units. Untreated areas would remain at a higher risk of insect and disease caused mortality, especially during periods of drought.

When planning thinning treatments, it should be recognized that the target stand density is an average to be applied across the landscape and some variability may be desired. Individual high value trees, such as mature pines, should benefit by having the stocking around them reduced to lower levels. Allowing for denser tree spacing and pockets of higher canopy cover may be desirable around potential wildlife trees, such as forked and/or broken-topped trees. This type of approach would also be consistent with the Region 5 Ecological Restoration Strategic Priority.

When implementing thinning projects, retaining more drought tolerant species such as ponderosa pine, Jeffrey pine, sugar pine, Douglas-fir and incense cedar over white fir will increase species diversity and make stands more resilient to disturbance. In addition, when selecting trees for removal, preference should be given to trees heavily infected with dwarf mistletoe, root disease and trees infested with bark beetles. Small group selections could be utilized to remove true fir that are within known Heterobasidion root disease centers and/or are heavily infected with dwarf mistletoe. This would create openings that could be planted with non-host species.

The defoliated white fir stands, caused by the Douglas-fir tussock moth, at the west end of the Diamond Mountain project area have now experienced three outbreaks (1964-1966, 1987 and 2013-2014). These stands are highly susceptible to outbreaks because they contain high levels of white fir, have multiple canopy layers and are growing on a dry upper south facing slope and ridgetop. It also appears that these stands were more open and pine dominated prior to the fire

suppression era, another common attribute of stands that have experience outbreaks in California. To reduce the susceptibility of these stands to future outbreaks, thinning treatments should emphasize a substantial reduction in the white fir component. Treatments in these areas should also try to facilitate natural and/or artificial pine regeneration by removing groups of white fir.

Sugar and western white pine should be retained as much as possible during any thinning operation in order to preserve genetic diversity, especially white pine blister rust (*Cronartium ribicola*) resistant individuals. White pine blister rust, a non-native pathogen, has continued to weaken and kill these species over most of their range since its introduction into the Pacific Northwest in 1910. Identification and protection of local rust resistant trees for seed collection, if not already occurring, will aid in the future planting of rust resistant seedlings. Planting selected openings created through thinning operations with rust resistant stock would help insure these species persists in the area.

Radial thinning and/or creating small openings around or adjacent to western white pine should be considered to increase the health and vigor of individual trees and to encourage the establishment of natural regeneration. Prescribed fire may also be necessary to increase the chance of successful western white pine seedling establishment.

It is recommended that a registered borate compound be applied to all freshly cut conifer stumps >14" to reduce the chance of creating new infection centers of *Heterobasidion irregulare*, formerly referred to as P-type annosus root disease and *Heterobasidion occidentale*, formerly referred to as S-type annosus root disease.

Considerations for Rx fire

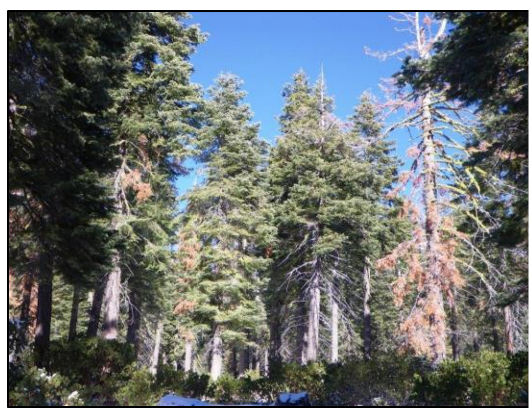


Figure 3. Dead and dying fire-injured white fir burned in a prescribed fire within the adjacent Wildcat project area (PNF).

If prescribed fire is used as a follow-up treatment to stand thinning or as a standalone treatment, unacceptable levels of large diameter pine mortality may occur depending on management objectives. This mortality most often occurs as a direct result of cambium or crown injury to individual trees during the fire. Mature Jeffrey, ponderosa and especially sugar pines are susceptible to mortality during prescribed burns because of the deep duff and litter that has accumulated at their base in the absence of fire. These duff mounds typically burn at a slow rate, while maintaining lethal temperatures, causing severe cambium injury. To protect individual large diameter pine from lethal cambium injury, raking the duff away from the bases of these trees before burning (within 24" of the bole and down to mineral soil) is recommended.

White fir dominated stands tend to have very high levels of course woody debris on the forest floor as a result of downed logs from self-thinning, the continual shedding of branches and the

remaining stems from old stands of brush that have been overtopped and killed by dense fir canopies. These types of stands produce tremendous amounts of heat on the ground surface and often cause severe injuries to the boles and crowns of standing trees, especially to smaller diameter trees. If high post-burn mortality levels in white fir stands, resulting in openings and possibly additional heavy fuel loading, is not an acceptable condition, than fuel treatments such as hand or tractor piling should be considered prior to or in place of prescribed fire. An example of post-prescribed fire white fir mortality exists at the north end of the adjacent Wildcat project area (Plumas NF) along FS Road 29N99 (Figure 3).

Considerations for aspen

Conifers within and adjacent to aspen stands provide a seed source that, in the absence of fire, can lead to greater conifer abundance at the expense of aspen. Mature white fir produce abundant amounts of seed and can readily establish within a shaded aspen stand (Pierce and Taylor 2010). Lodgepole pine also produces abundant seed and is moderately shade tolerant. Lodgepole pine regeneration can be especially abundant where ground disturbance from harvest activity has provided bare soil for seed to germinate. Ponderosa and Jeffrey pine are not easily established in shaded areas and generally require disturbance that creates canopy openings and bare mineral soil for seed germination (Forest Effects Information System [FEIS] database).

Insect and disease agents on aspen in the Diamond Mountains are impacting aspen health far less than the existing conifer encroachment. While it is important for the District to be aware of the potential for damage by these agents, the impacts of conifer encroachment are of a more imminent concern. Once aspen stands are treated by removing conifers and protecting regeneration (if necessary), vigorous stands will be more resilient to the impacts of any native insect or disease.

Potential for FHP Funding

Forest Health Protection may be able to assist with funding, including NEPA, for thinning and removing green material from overstocked areas within the Diamond Mountain project area. Thinning projects in this area would meet the minimum requirements for western bark beetle funding and are supported by this evaluation. If you are interested in this competitive funding please contact me for assistance in developing and submitting a proposal.

If you have any questions regarding this report and/or need additional information please contact Danny Cluck at 530-252-6431.

/s/ Danny Cluck

Daniel R. Cluck
Forest Entomologist
NE CA Shared Services Area

cc: Bobette Jones, Ecologist, Eagle Lake RD
Scott Stawiarski, Forest Silviculturist, Lassen SO
Forest Health Protection, Regional Office

Insect and Disease Information

Western Pine Beetle

The western pine beetle, *Dendroctonus brevicomis*, has been intensively studied and has proven to be an important factor in the ecology and management of ponderosa pine throughout the range of this host species (Miller and Keen 1960). This insect breeds in the main bole of living ponderosa pine larger than about 8 inches dbh. Normally it breeds in trees weakened by drought, overstocking, root disease, dwarf mistletoe or fire. Adult beetles emerge and attack trees continuously from spring through fall. Depending on the latitude and elevation, there can be from one to four generations per year.

Evidence of Attack

Initial attacks are made about mid-bole and subsequent attacks fill in above and below. Pitch tubes are formed on the tree trunk around the entry holes. The pitch tubes are red-brown masses of resin and boring dust. Relatively few, widely scattered, white pitch tubes usually indicate that the attacks were not successful and that the tree should survive. Pheromones released during a successful attack attract other western pine beetles. Attacking beetles may spill over into nearby apparently healthy trees and overwhelm them by sheer numbers.

Life Stages and Development

These beetles pass through the egg, larval, pupal and adult stages during a life-cycle that varies in length dependent primarily upon temperature. Adults bore a sinuous gallery pattern in the phloem and the female lays eggs in niches along the sides of the gallery. The larvae are small white grubs that first feed in the phloem and then mine into the middle bark where they complete most of their development. Bluestain fungi, introduced during successful attacks, contribute to the rapid tree mortality associated with bark beetle attacks.

Conditions Affecting Outbreaks

Outbreaks of western pine beetle have been observed, and surveys made, in pine regions of the West since 1899 (Hopkins 1899; cited in Miller and Keen 1960). An insect survey completed in 1917 in northern California indicated that over 25 million board feet of pine timber had been killed by bark beetles. Information from surveys initiated in the 1930s indicates that there were enormous losses attributed to western pine beetle around that time. During the 1930's outbreak, most of the mortality occurred in stands of mature or overmature trees of poor vigor (Miller and Keen 1960). Group kills do not typically continue to increase in size through successive beetle generations as is typical with Jeffrey pine beetle. Rather, observations indicate that emerging beetles tend to leave the group kill area to initiate new attacks elsewhere.

The availability of suitable host material is a key condition influencing western pine beetle outbreaks. In northeastern California, drought stress may be the key condition influencing outbreaks. When healthy trees undergo a sudden and severe moisture stress populations of western pine beetle are likely to increase. Healthy trees ordinarily produce abundant amounts of resin, which pitch out attacking beetles, but when deprived of moisture, stressed trees cannot produce sufficient resin flow to resist attack. Any condition that results in excessive demand for moisture, such as tree crowding, competing vegetation or protracted drought periods; or any condition that reduces that ability of the roots to supply water to the tree, such as mechanical damage, root disease, or soil compaction, can cause moisture stress and increase

susceptibility to attack by the western pine beetle. Woodpeckers and predaceous beetles are natural control agents when beetle populations are low.

Jeffrey pine beetle

The Jeffrey pine beetle is the principle bark beetle found attacking Jeffrey pine, which is its only host. It is a native insect occurring from southwestern Oregon southward through California and western Nevada to northern Mexico. The beetle normally breeds in slow-growing, stressed trees. The beetles prefer trees which are large, mature, and occur singly rather than in groups. Yet when an epidemic occurs, the beetle may attack and kill groups of trees greater than 8 inches in diameter, regardless of age or vigor. Often the beetle infests lightning-struck or wind-thrown trees, but does not breed in slash.

Evidence of Attack

Presence of the beetle is usually detected when the foliage changes color. The color change of the foliage is related to the destruction of the cambium layer by the beetle. Generally, the top of the crown begins to fade in a slow sequence, with the needles turning from greenish yellow, to sorrel, and finally to reddish brown. By the time the tree is reddish brown, the beetles have usually abandoned the tree. Another sign of beetle attack is large, reddish pitch tubes projecting from the bark of the infested tree. If examined carefully, pitch tubes can be detected on infested green trees prior to crown fade. Jeffrey pine beetles have a distinctive "J" shape egg gallery pattern on the inner bark. Larval mines extend across the grain and end in open, oval-shaped pupal cells.

Life Stages and Development

The Jeffrey pine beetle is one of the larger pine bark beetles in California. The beetle has a 4 life stages, egg, larva, pupa, and adult. The adults are stout, cylindrical, black, and approximately five-sixteenths of an inch long when mature. The egg is oval and pearly-white. The larva is white, legless, and has a yellow head. The pupa is also white but is slightly smaller than the mature larva. The life cycle is normally completed in one year in the northern part of the range, but in the southern part, two generations per year may occur. The principle period of attack is in June and July, but attacks also are frequent in late September and early October. Similar to other *Dendroctonus* species, Jeffrey pine beetles use pheromones that attract other beetles to a tree, causing a mass attack that tends to overcome the tree's natural resistance. Blue stain fungi are associated with Jeffrey pine beetle attacks and aid in overcoming the tree's defenses.

Conditions Affecting Outbreaks

Normally the Jeffrey pine beetle is kept in check by its natural enemies, climatic factors and the resistance of its host. Similar to other *Dendroctonus* species, the availability of suitable host material is a key factor influencing outbreaks. Healthy trees ordinarily produce abundant amounts of resin, which pitches out attacking beetles. When deprived of moisture, or stressed by other factors such as disease or fire injury, trees cannot produce sufficient resin flow and become susceptible to successful beetle attacks.

Fir engraver beetle

The fir engraver attacks red and white fir in California. Fir engraver adults and developing broods kill true firs by mining the cambium, phloem, and outer sapwood of the bole, thereby girdling the tree. Trees greater than 4" in diameter are attacked and often killed in a single season. Many trees, weakened through successive attacks, die slowly over a period of years. Others may survive attack as evidenced by old spike-topped fir and trees with individual branch mortality. Although many other species of bark

beetles cannot develop successful broods without killing the tree, the fir engraver beetle is able to attack and establish broods when only a portion of the cambium area has been killed.

Evidence of Attack

Fir engravers bore entrance holes along the main stem, usually in areas that are > 4" in diameter. Reddish-brown or white boring dust may be seen along the trunk in bark crevices and in spider webs. Some pitch streamers may be indicative of fir engraver attacks; however, true firs are known to stream pitch for various reasons and there is not clear evidence that pitch streamers indicate subsequent tree mortality or successful attack. Resin canals and pockets in the cortex of the bark are part of the trees defense mechanism. Beetle galleries that contact these structures almost always fail to produce larval galleries as the adults invariably abandon the attack. Pitch tubes, often formed when bark beetles attack pine, are not produced on firs.

Adults excavate horizontal galleries that engrave the sapwood; the larval galleries extend at right angles along the grain. Attacks in the crown may girdle branches resulting in individual branch mortality or "flagging". Numerous attacks over part or the entire bole may kill the upper portion of the crown or the entire tree. A healthy tree can recover if sufficient areas of cambium remain and top-killed trees can produce new leaders. The fir engraver is frequently associated with the roundheaded fir borer and the fir flatheaded borer.

Life Stages and Development

In the summer, adults emerge and attack new host trees. The female enters the tree first followed by the male. Eggs are laid in niches on either side of the gallery. Adult beetles carry the brown staining fungi, *Trichosporium symbioticum*, into the tree that causes a yellowish-brown discoloration around the gallery. The larvae mine straight up and down, perpendicular to the egg gallery. Winter is commonly spent in the larval stage, with pupation occurring in early spring. In most locations, the fir engraver completes its life cycle in 1 year; however at higher elevations 2 years may be required.

Conditions Affecting Outbreaks

Fir engravers bore into any member of the host species on which they land but establish successful galleries only in those that have little or no resistance to attack. Populations of less aggressive species like fir engraver are likely to wax and wane in direct relationship to the stresses of their hosts. Drought conditions often result in widespread fir mortality; however, attempting to determine when outbreaks will occur is difficult. Lowered resistance of trees appears to be a contributing factor. Overstocking and the increased presence of fir on sites that were once occupied by pine species may also contribute to higher than normal levels of fir mortality. Several insect predators, parasites and woodpeckers are commonly associated with the fir engraver and may help in control of populations at endemic levels.

Mountain pine beetle

The mountain pine beetle, *Dendroctonus ponderosae,* attacks the bole of ponderosa, lodgepole, sugar and western white pines larger than about 8 inches dbh. Extensive infestations have occurred in mature lodgepole pine forests. Group killing often occurs in mature forests and young overstocked stands of ponderosa, sugar and western white pines.

Evidence of Attack

The first sign of beetle-caused mortality is generally discolored foliage. The mountain pine beetle begins attacking most pine species on the lower 15 feet of the bole. Examination of infested trees usually reveals the presence of pitch tubes. Pitch tubes on successfully infested trees are pink to dark red masses of resin mixed with boring dust. Creamy, white pitch tubes indicate that the tree was able to "pitch out" the beetle

and the attack was not successful. In addition to pitch tubes, successfully infested trees will have dry boring dust in the bark crevices and around the base of the tree. Attacking beetles carry the spores of blue-staining fungi which develop and spread throughout the sapwood interrupting the flow of water to the crown. The fungi also reduces the flow of pitch in the tree, thus aiding the beetles in overcoming the tree. The combined action of both beetles and fungi causes the needles to discolor and the tree to die.

Life Stages and Development

The beetle develops through four stages: egg, larva, pupa and adult. The life cycle of the mountain pine beetle varies considerably over its range. One generation per year is typical, with attacks occurring from late June through August. Two generations per year may develop in low elevation sugar pine. Females making their first attacks release aggregating pheromones. These pheromones attract males and other females until a mass attack overcomes the tree. The adults bore long, vertical, egg galleries and lay eggs in niches along the sides of the gallery. The larvae feed in mines perpendicular to the main gallery and construct small pupal cells at the end of these mines where they pupate and transform into adults.

Conditions Affecting Outbreaks

The food supply regulates populations of the beetle. In lodgepole pine, it appears that the beetles select larger trees with thick phloem, however the relationship between beetle populations and phloem thickness in other hosts has not been established. A copious pitch flow from the pines can prevent successful attack. The number of beetles, the characteristics of the tree, and the weather affect the tree's ability to produce enough resin to resist attack. Other factors affecting the abundance of the mountain pine beetle include nematodes, woodpeckers, and predaceous and parasitic insects. As stand susceptibility to the beetle increases because of age, overstocking, diseases or drought, the effectiveness of natural control decreases and pine mortality increases.

Douglas-fir Tussock Moth

The Douglas-fir tussock moth is an important defoliator of true firs, primarily white fir, in California. Some level of outbreak by Douglas-fir tussock moth has been recorded in California about every 10 years. Outbreaks appear to develop almost explosively, and then usually subside abruptly after a year or two. Defoliation by the tussock moth kills or top-kills many trees, weakens additional trees that can be eventually killed by bark beetles, and may retard tree growth for several years.

Usually the first indication of attack appears in late spring. Larvae from the newly hatched eggs feed on current year's foliage, causing it to shrivel and turn brown. Older larvae may feed on both current and old foliage, although current needles are preferred. Defoliation occurs first in the tops of the trees and the outermost portions of the branches, and then in the lower crown and farther back on the branches.

The adult male is a gray-brouwn to black-brown moth with feathery antennae and a wingspread of 1 to 1 1/4 inches. The forewings are gray brown and have two distinct, irregular dark bars and two vague whitish spots. The hindwings are a contrasting brown. The female has tiny rudimentary wings, small threadlike antennae, and a large abdomen. Young larvae are 1/8 to 1/4 inch long and have long, fine body hairs which later develop into tufts. Mature larvae are up to 1 1/4 inches long and very colorful. Two long, dark tufts or pencils of hair similar to horns are located right behind the head. Four dense, buff colored tussocks are located forward along the middle of the back. The rest of the body except for the legs and head, is covered with short hairs radiating from red, buttonlike centers.

The tussock moth produces one generation each year. Females mate soon after they emerge from their pupal cocoon. Egg hatch in May or early June coincides with bud burst and shoot elongation of the host trees. The larvae pass through four to six instars and pupate toward the end of the summer. The pupal stage lasts from 10-18 days depending on temperature.

Many natural controls exist that keep the number of tussock moths low most of the time. If population levels are causing unacceptable resource damage, alternate methods of control are available. Management recommendations to prevent tree damage from tussock moth outbreaks involve four major activities: early detection, evaluation, suppression, and prevention. An early detection pheromone trap monitoring system is in place in California, however prevention is the ultimate goal of pest management. Silvicultural systems that reduce the number of susceptible hosts and decrease the multi-storied characteristics of host stands are recommended to prevent outbreaks. There is some indication that fir growing in pine sites an fir stands on warm, dry sites are most susceptible to damage.

Heterobasidion root disease

Heterobasidion spp. is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone (*Arbutus menziesii*), and a few brush species (*Arctostaphylos spp.* and *Artemisia tridentata*) are occasional hosts. Other hardwood species are apparently not infected. The disease has been reported on all National Forests in California, with incidence particularly high on true fir in northern California, in the eastside pine type forests, and in southern California recreation areas.

Heterobasidion root disease is one of the most important conifer diseases in Region 5. Current estimates are that the disease infests about 2 million acres of commercial forestland in California, resulting in an annual volume loss of 19 million cubic feet. Other potential impacts of the disease include: increased susceptibility of infected trees to attack by bark beetles, mortality of infected trees presently on the site, the loss of the site for future production, and depletion of vegetative cover and increased probability of tree failure and hazard in recreation areas.

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers are initiated when airborne spores produced by the conks land and grow on freshly cut stump surfaces. Infection in true fir may also occur through fire and mechanical wounds, or occasionally, through roots of stumps in the absence of surface colonization. From the infected stump surface, the fungus grows down into the roots and then spreads via root-to-root contact to adjacent live trees, resulting in the formation of large disease centers. These infection centers may continue to enlarge until they reach barriers, such as openings in the stand or groups of resistant plants. In pines, the fungus grows through root cambial tissue to the root crown where it girdles and kills the tree. In true fir and other non-resinous species, the fungus sometimes kills trees, but more frequently is confined to the heartwood and inner sapwood of the larger roots. It then eventually extends into the heartwood of the lower trunk and causes chronic decay and growth loss.

Heterobasidion root disease in western North America is caused by two species: *Heterobasidion occidentale* (also called the 'S' type) and *H. irregulare* (also called the 'P' type). These two species of *Heterobasidion* have major differences in host specificity. *H. irregulare* (‘P’ type) is pathogenic on ponderosa pine, Jeffrey pine, sugar pine, Coulter pine, incense cedar, western juniper, pinyon, and manzanita. *H. occidentale* (‘S’ type) is pathogenic on true fir, spruce and giant sequoia. This host specificity is not apparent in isolates from stumps; with *H. occidentale* being recovered from both pine and true fir stumps. These data suggest that infection of host trees is specific, but saprophytic

colonization of stumps is not. The fungus may survive in infected roots or stumps for many years. Young conifers established near these stumps often die shortly after their roots contact infected roots in the soil.

Dwarf mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic, flowering plants that can only survive on living conifers in the Pinaceae. They obtain most of their nutrients and all of their water and minerals from their hosts.

Dwarf mistletoes spread by means of seed. In the fall the fruit ripen and fall from the aerial shoots. The seeds are forcibly discharged. The seed is covered with a sticky substance and adheres to whatever it contacts. When a seed lands in a host tree crown, it usually sticks to a needle or twig, where it remains throughout the winter. The following spring the seed germinates and penetrates the twig at the base of the needle. For the next 2-4 years, the parasite grows within the host tissues, developing a root-like system within the inner bark and outer sapwood, and causing the twig or branch to swell. Aerial shoots then develop and bear seed in another 2-4 years.

Dispersal of dwarf mistletoe seeds is limited to the distance the seeds travel after being discharged. From overstory to understory, this is usually 20 to 60 feet, but wind may carry them as far as 100 feet from the source. A rule of thumb is that the seeds can travel a horizontal distance equal to the height of the highest plant in an infected tree. There is some evidence that long distance spread of dwarf mistletoe is occassionaly vectored by birds and animals.

Vertical spread within tree crowns of most dwarf mistletoes is limited to less than one foot per year because of foliage density. Because of the thin crowns of gray pine, however, the vertical rate of spread has been measured as being greater than 2 feet per year. This rate of spread equalled or exceeded the rate of height growth of infected trees.

Dwarf mistletoes are easy to identify because they are generally exposed to view within a tree's crown. Signs of infection include the yellow-green to orange mistletoe plants, basal cups on a branch or stem where the plants were attached and detached plants on the ground beneath an infected tree. Symptoms include spindle-shaped branch swellings, witches' brooms in the lower crown, and bole swellings.

White pine blister rust

White pine blister rust is caused by *Cronartium ribicola* an obligate parasite that attacks 5-needled pines and several species of *Ribes* spp. The fungus needs the two alternate hosts to survive, spending part of its life on 5-needled pines and the other on *Ribes* spp. The disease occurs throughout the range of sugar pine to the southern Sierra Nevada, but has not been reported further south. Infection of pines results in cankers on branches and main stems, branch mortality, top kill, and tree mortality.

Spores (aeciospores) produced by the fungus in the spring on pine bole or branch cankers are wind-disseminated to *Ribes* spp. where they infect the leaves. Spores (urediospores) produced in orange pustules on the underside of the leaves reinfect other *Ribes* spp. throughout the summer, resulting in an intensification of the rust. A telial spore stage forms on *Ribes* spp. leaves in the fall. Teliospores germinate in place to produce spores (sporida) which are wind-disseminated to pines and infect current year needles. Following infection, the fungus grows from the needle into the branch and forms a canker.

After 2 or 3 years, spores are produced on the cankers and are spread to *Ribes* spp. to continue the cycle. Although blister rust may spread hundreds of miles from pines to *Ribes* spp., its spread from *Ribes* spp. back to pines is usually limited to a few hundred feet.

Branch cankers continue to enlarge as the fungus invades additional tissues and moves toward the bole. Branch cankers within 24 inches of the bole will eventually form bole cankers. Bole cankers result in girdling and death of the tree above the canker. Cankers that have margins more than 24 inches from the main bole are unlikely to reach the bole and only branch flagging will result.